367.38589X00

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s):   Andy PHELPS

Serial No.:

Filed: May 23, 2000

Title: AUDIO APPARATUS

Group:

LETTER CLAIMING RIGHT OF PRIORITY

Honorable Commissioner of   May 23, 2000
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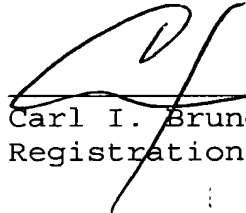Washington, D.C. 20231

Sir:

    Under the provisions of 35 USC 119 and 37 CFR 1.55, the

applicant(s) hereby claim(s) the right of priority based on

Great Britain Patent Application No.(s) 9913848.9 filed June

14, 1999.

    A certified copy of said Great Britain Application is

attached.

                    Respectfully submitted,

                    ANTONELLI, TERRY, STOUT & KRAUS, LLP

                    Carl I. Brundidge
                    Registration No. 29,621

CIB/nac
Attachment
(703) 312-6600

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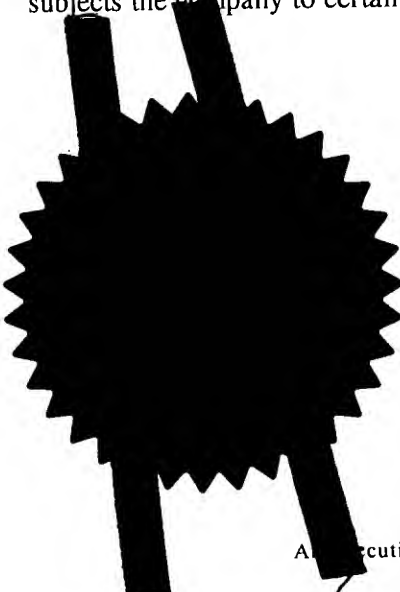
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The Patent
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15JUN99 E454623-1 D02716_____
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Request for grant of a patent

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an explanatory leaflet from the Patent Office to help
you fill in this form)

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1.	Your reference	PAT 99009 GB

2.	Patent application number *(The Patent Office will fill in this part)*	**'14 JUN 1999**	**9913848.9**

3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	NOKIA MOBILE PHONES LIMITED KEILALAHDENTIE 4 02150 ESPOO FINLAND
	Patents ADP number *(if you know it)* 7406747001 *Rdes*	
	If the applicant is a corporate body, give the country/state of its incorporation	FINLAND

4.	Title of the invention	AUDIO APPARATUS

5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	NOKIA IPR DEPARTMENT NOKIA HOUSE SUMMIT AVENUE FARNBOROUGH HAMPSHIRE GU14 0NG UK
	Patents ADP number *(if you know it)*	7577638001 ✓

		Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number			

		Number of earlier application	Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application		

8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* a) *any applicant named in part 3 is not an inventor, or* b) *there is an inventor who is not named as an applicant, or* c) *any named applicant is a corporate body.* *See note (d))*	YES

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Continuation sheets of this form

Description   9

Claim(s)   2

Abstract   1

Drawing(s)   4 + 4

10. If you are also filing any of the following,
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Priority documents

Translations of priority documents

Statement of inventorship and right
to grant of a patent *(Patents Form 7/77)*

Request for preliminary examination
and search *(Patents Form 9/77)*   1

Request for substantive examination
(Patents Form 10/77)

Any other documents
(please specify)

11.   I/We request the grant of a patent on the basis of this application.

Signature   *Juliet Hibbert*   Date 14/06/99

JULIET HIBBERT

12. Name and daytime telephone number of
    person to contact in the United Kingdom   CHRIS HARRISON 01252 866000

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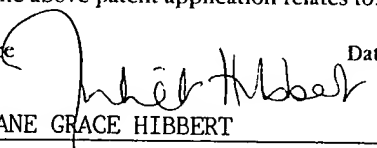(Rule 1)

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Statement of inventorship and of right to grant of a patent

The Patent Office

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1.	Your reference	PAT 99009 GB
2.	Patent application number *(if you know it)*	9913848.9
3.	Full name of the or of each applicant	NOKIA MOBILE PHONES LIMITED KEILALAHDENTIE 4 02150 ESPOO FINLAND
4.	Title of the invention	AUDIO APPARATUS
5.	State how the applicant(s) derived the right from the inventor(s) to be granted a patent	BY VIRTUE OF SECTION 7(2)(c).
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7.

I/We believe that the person(s) named over the page *(and on any extra copies of this form)* is/are the inventor(s) of the invention which the above patent application relates to.

Signature Date 9/7/99

JULIET JANE GRACE HIBBERT

8. Name and daytime telephone number of person to contact in the United Kingdom

CHRIS HARRISON 01252 865037

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057 55 . /0

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Enter the full names, addresses and postcodes of the inventors in the boxes and underline the surnames

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SO15 5FP

7698707001

Patents ADP number *(if you know it):*

Patents ADP number *(if you know it):*

Patents ADP number *(if you know it):*

Reminder

Have you signed the form?

PAT 99009 GB

AUDIO APPARATUS

5   This invention relates to audio apparatus, and in particular audio apparatus for radiating an ultrasonic pressure wave with a modulated audio signal.

Audio spotlighting, using a parametric audio system, provides a means for projecting highly directional beams of audible sound. This technology employs

10   the non-linearity of a compressible material (such as air) to create audible by-products from inaudible ultrasound. This technique exploits an acoustic phenomenon called self-demodulation where low frequency audio beams of high directivity are generated from a high amplitude ultrasonic beam that has been modulated with an audio signal. Self-demodulation generates new

15   frequencies in the received sound spectra based on the envelope frequency (i.e. the required audio signal) in a process akin to AM demodulation. Thus this technique provides a beam of audio sound with the focused directional properties of the original ultrasonic carrier beam, allowing distant targeting of specific listeners. This technique can produce predictable and controllable

20   levels of audio sound and, despite the relatively weak effect of self-demodulation, is capable of generating substantial sound amplitudes due to the narrow spatial distribution of the acoustic energy.

The transmitted modulated ultrasonic wave can be considered as a collimated

25   primary wave consisting of an amplitude modulated wave of pressure where the primary pressure wave is defined by

1) $p_1 = P_1 E(t) \sin(\omega_c t)$

where P_1 is the amplitude of the primary beam pressure, ω_c is the carrier frequency and E(t) is the modulation envelope. For an amplitude modulated signal E(t) is equal to (1 + mg(t)) where m is the modulation depth and g(t) is the audio signal.

As a result of p_1 interacting with the air the modulated audio signal demodulates creating an audible secondary pressure wave p_2 given by

$$2) \qquad p_2(t) = \frac{\beta P_1^2 A}{16\pi\rho_0 c_0^4 z\alpha} \frac{\partial^2}{\partial t^2} E^2(\tau)$$

where β is the coefficient of nonlinearity (β_{air}= 1.2), ρ_0 is the ambient density of the medium, c_0 is the small signal wave propagation speed, A is the beam's cross-sectional area, z is the axial distance, α is the absorption coefficient of the medium. So, for example, where c=343 m/s, ρ_0 =1.2kg/m^3 , α = 0.6, and A=5x10m^{-3}, a 140dB ultrasound wave modulated with a 1kHz signal would produce about 71dB of audible sound at 1m.

The power of the resultant audio signal is proportional to the second derivative of the square of the modulation envelope. As a result significant coloration (i.e. a shift of signal power with respect to frequency) and distortion are introduced onto the demodulated audio signal as a result of the interaction of the ultrasonic wave with the non-linear medium. The coloration of the signal results in the low frequency audio components being suppressed by approximately 12dB/octave; this is represented by the second derivative term of the modulation envelope. The distortion of the signal is represented by the square of the modulation envelope.

Processing the audio signal prior to modulation can minimise the effects of coloration and distortion that result from the interaction of the ultrasonic wave

with the non-linear medium. The processing typically comprises a double integration filter to compensate for coloration of the audio signal and a square root operation to compensate for the distortion of the audio signal.

5   However, for the self-demodulation to occur high ultrasonic sound pressure levels are required. To generate these high pressure levels it is necessary to generate the ultrasonic pressure levels at or close to the resonant frequency of the transmitting transducer. Correspondingly the frequency response of the transducer can vary dramatically at this frequency. The variable transducer

10   frequency response can significantly affect the quality of the demodulated audio pressure wave.

Figure 1, plot A shows the frequency spectrum of a white noise input signal constrained between 300 and 4000 Hz prior to modulation with an ultrasonic

15   carrier signal. An example of the effects of self-demodulation and transducer conversion upon the input signal, using a typical transducer having a measured frequency response shown in figure 2, is shown in figure 1, plot B.

The frequency response of a transducer can be flattened at the resonant

20   frequency. However this requires considerable damping to be added to the transducer, and a corresponding drop in ultrasonic pressure level. This in turn would require a transducer with a large radiating surface area, which is not suitable for small devices, for example a mobile communication device and in particular a radiotelephone.

25

In accordance with an aspect of the present invention there is provided audio apparatus comprising a modulator for modulating a first ultrasonic signal with an audio signal to provide a second ultrasonic signal; a transducer for converting the second ultrasonic signal into an ultrasonic pressure wave for

30   transmission into a non-linear medium to allow demodulation of the ultrasonic

pressure wave and thereby generate an audio pressure wave representative of the audio signal; processing means for modifying the audio signal to compensate for the demodulating properties of the non-linear medium; and means for modifying the audio signal to compensate for the conversion

5 characteristics of the transducer.

This provides the advantage of enabling the effects of the demodulation process and the transducer conversion characteristics on the audio signal to be minimised. This can allow the size of the transducer to be reduced while

10 retaining the performance of the transducer.

Typically the means for modifying the audio signal to compensate for the conversion characteristics of a transducer is a transducer response filter.

15 Most preferably the processing means comprises a double integration filter and a square root operator. As the operator processes the audio signal non-linearly the characteristics of the second filter are preferably derived empirically by tone adjustment for the required frequency range of the audio signal.

20

The invention will now be described, by way of one example only, with reference to the accompanying drawings, in which:

Figure 1, plot A shows the frequency spectrum of a test audio input signal to

25 an audio apparatus according to one embodiment of the present invention;

Figure 1, plot B shows the frequency spectrum of figure 1, plot A after self-demodulation without correction;

Figure 2 shows a typical measured frequency response of a suitable transducer for use in audio apparatus according to an embodiment of the present invention;

5   Figure 3 shows a radiotelephone having audio apparatus according to an embodiment of the present invention;

Figure 4 shows audio apparatus according to an embodiment of the present invention;

10

Figure 5, plot A shows the frequency spectrum of the test audio signal output after self-demodulation with correction for self-demodulation;

Figure 5, plot B shows the frequency spectrum of the test audio signal output

15   from audio apparatus according to an embodiment of the present invention.

Figure 3 shows a radiotelephone 1 with audio apparatus 2, a speech decoder 3, a channel decoder 4, a receiver 5 and an antenna 6. In operation the receiver 5 receives a speech encoded digital signal 20 from a base station

20   (not shown) via antenna 6. The receiver 5 demodulates the received digital signal 20 and passes the demodulated signal 21 to channel decoder 4 which corrects for errors that may have occurred during the transmission process by using error protection bits encoded within the received signal. The receiver 5 typically samples the received signal 20 at 8 kHz. The decoded digital signal

25   22 is provided to speech decoder 3 which decodes the speech and passes the digital decoded signal 23 to audio apparatus 2 to generate an acoustic representation of the received speech signal as described in detail below. The audio apparatus 2 may be mounted within the radiotelephone 1. Typically however, to obtain the required audio power levels and to support hands free

30   use of the radiotelephone 1, the audio apparatus 2 is mounted separately to

the radiotelephone 1, for example, in conjunction with a hands free kit or a car kit for hands free use of a radiotelephone in a car.

Figure 4 shows the audio apparatus 2 which comprises a double integration
5   filter 7, a transducer response filter 8, a DC shifter 9, an up-sampler 10, a square root operator 11, a modulator 12, an ultrasonic signal source 13, a digital to analogue converter 14 and an ultrasonic transducer 15.

The audio apparatus 2 is a parametric device that radiates an inaudible
10   ultrasonic pressure wave with an audio signal modulated onto the ultrasonic pressure wave. The transmitted ultrasonic wave interacts with air (i.e. a compressible non-linear medium) to cause the ultrasonic wave to self-demodulate, thereby causing the modulated audio signal to become audible.

15   Digital signal 23 is provided to double integration filter 7, which boosts the low frequencies by 12 dB/octave akin to integrating the signal twice. Double integration filter 7 compensates for the effects of coloration that occur during the self-demodulation process, and is linear in nature. Typically, the double integration filter 7 is a simple recursive filter. The double integration filter 7
20   provides the double integrated digital signal 24 to transducer response filter 8.

The transducer response filter 8 corrects for characteristics of the ultrasonic transducer 15, as described in detail below. The transducer response filter 8 provides the corrected signal 25 to DC shifter 9.
25

The DC shifter 9 re-scales the data and shifts the voltage of the corrected digital signal 25 so that all signal voltages are positive, thus ensuring the square root operation only has to work on positive values, thereby avoiding complex filtering.
30

The DC shifted signal 26 is provided to up-sampler 10. The up-sampler 10 re-samples the 8 kHz signal at typically 120 kHz. The purpose of up-sampler 10 is to increase the frequency range of the signal in preparation for the square rooting of the signal. A consequence of square rooting the received signal is

5   the creation of an infinite series of harmonics. For distortion to be eliminated all these harmonics must be reproduced. Therefore, to ensure harmonics above 4 kHz are reproduced the signal is re-sampled at a higher frequency. Sample rates other than 120 kHz may be used dependant on the operating frequencies of the ultrasonic transducer. The re-sampled signal 27 is provided

10   to the square root operator 11.

The square rooting operator 11 compensates for the effects of distortion that occur during the self-demodulation process, and is non-linear in nature.

15   The square root operator 11 is typically performed by means of a look up table, as is well known to a person skilled in the art.

The square rooted signal 28 is provided to modulator 12 for modulation with an ultrasonic signal 29 from ultrasonic signal source 13. To minimise the risk

20   of harm to humans or animals the ultrasonic frequency should be higher than approximately 40kHz. Due to increased signal absorption by the air at higher frequencies the upper highest feasible frequency limit is typically of the order of 200kHz.

25   The digital modulated ultrasonic signal 30 is provided to digital to analogue converter 14 for converting the digital signal 30 to a representative analogue signal. The analogue modulated ultrasonic signal 31 is provided to ultrasonic transducer 15. Transducer 15 radiates the modulated ultrasonic signal as an inaudible ultrasonic pressure wave.

30

To obtain the required ultrasonic pressure levels required for self-demodulation to occur the transducer 15 will typically be chosen to have its resonance frequency at the frequency of the ultrasonic carrier signal 29.

5   For a 40 kHz ultrasonic signal a suitable transducer is the MuRata MA40B8S. This transducer has a frequency response as shown in figure 2, which has a narrow resonance band at 40 kHz. To obtain the required power levels a plurality of transducers will typically be required, for example 19 transducers will provide 55 dB's of audio speech signal.

10

As the square root operator 11 is non-linear it is not possible for the transducer response filter 8 to have a single optimum filtering characteristic for all frequencies. Therefore, the transducer response filter 8 is determined empirically for a required frequency range. For example, if the resultant

15   spectra of the self-demodulated signal shows a gradual power drop from 300 Hz to 4 kHz after correction for self-demodulation, the transducer response filter 8 is selected to boost the signal over this frequency range. The characteristics of the transducer response filter are therefore, typically, the inverse response of the resultant spectra of the self-demodulated signal. The

20   transducer response filter is designed typically using a recursive filter design package, for example the Yule-Walk package, which models the transducer response filter characteristics using the inverse of the self-demodulated signal.

25   Typically the transducer response filter characteristics are determined during the manufacture of the audio device. However, it is possible for the characteristics of the transducer response filter to be determined dynamically, for example while during use of the audio device.

Figure 5, plot A shows the transducer conversion effect upon the input signal shown in figure 1, plot A. Figure 5, plot B shows the corrected spectrum using a transducer response filter 8 empirically derived using figure 5, plot A for determining the effect of the transducer conversion. For different frequency and modulation depths the square root non-linear operator 11 will vary the effects of the transducer conversion and accordingly different frequency and modulation depths will require the transducer response filter 8 to be modified empirically as described above.

The transducer response filter 8 is typically a simple recursive filter.

The present invention may include any novel feature or combination of features disclosed herein either explicitly or implicitly or any generalisation thereof irrespective of whether or not it relates to the presently claimed invention or mitigates any or all of the problems addressed. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention. The applicant hereby gives notice that new claims may be formulated to such features during prosecution of this application or of any such further application derived therefrom. For example, it will be appreciated that an analogue audio signal can be processed and modulated with an ultrasonic carrier signal, also that the pre-processing filters and/or operator can be used to process the audio signal after modulation of the audio signal.

CLAIMS

1. Audio apparatus comprising a modulator for modulating a first ultrasonic signal with an audio signal to provide a second ultrasonic signal; a transducer for converting the second ultrasonic signal into an ultrasonic pressure wave for transmission into a non-linear medium to allow demodulation of the ultrasonic pressure wave and thereby generate an audio pressure wave representative of the audio signal; processing means for modifying the audio signal to compensate for the demodulating properties of the non-linear medium; and means for modifying the audio signal to compensate for the conversion characteristics of the transducer.

2. Audio apparatus according to claim 1, wherein the first ultrasonic signal is amplitude modulated with the audio signal.

3. Audio apparatus according to claim 1 or 2, wherein the first ultrasonic signal is equal to or greater than 40 kHz.

4. Audio apparatus according to any preceding claim, wherein the processing means comprises a double integration filter and a square root operator.

5. Audio apparatus according to claim 4, wherein the means for modifying is disposed between the double integration filter and the square root operator.

6. Audio apparatus according to any of the preceding claims, wherein the means for modifying is a digital filter.
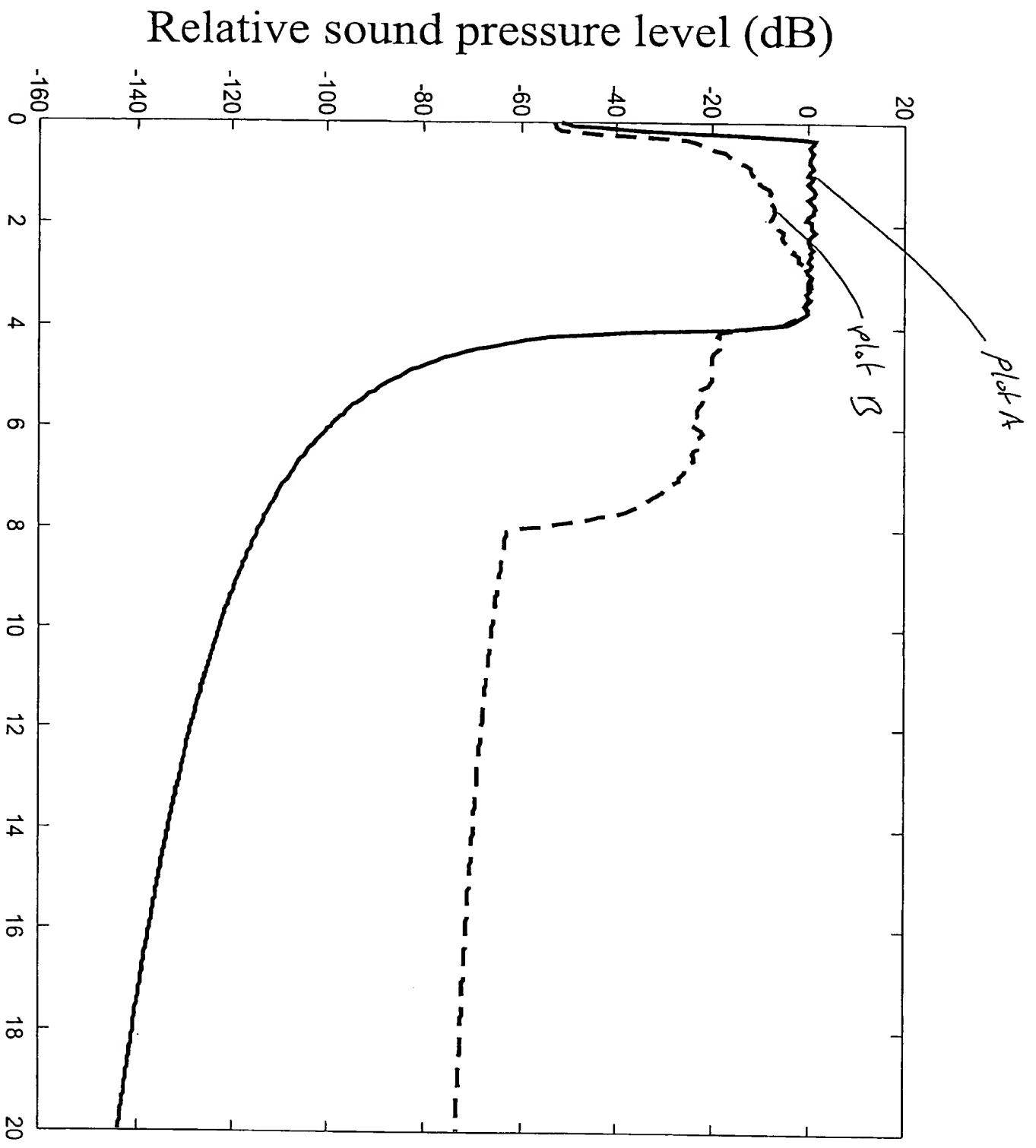
7. Audio apparatus according to any preceding claim, wherein the characteristics of the means for modifying are empirically derived by tone adjustment.

5   8. A radiotelephone having audio apparatus according to any of the preceding claims.

9. A portable radio device having audio apparatus according to any of the preceding claims.

10

10. Audio apparatus substantially as hereinbefore described with reference to the accompanying drawings, and/or as shown therein.

ABSTRACT

<u>AUDIO APPARATUS</u>

5   Audio apparatus comprising a modulator 12 for modulating a first ultrasonic signal 29 with an audio signal to provide a second ultrasonic signal 30; a transducer 15 for converting the second ultrasonic signal 30 into an ultrasonic pressure wave for transmission into a non-linear medium to allow demodulation of the ultrasonic pressure wave and thereby generate an audio

10   pressure wave representative of the audio signal 28; processing means 11 for modifying the audio signal to compensate for the demodulating properties of the non-linear medium; and means 8 for modifying the audio signal to compensate for the conversion characteristics of the transducer 15.
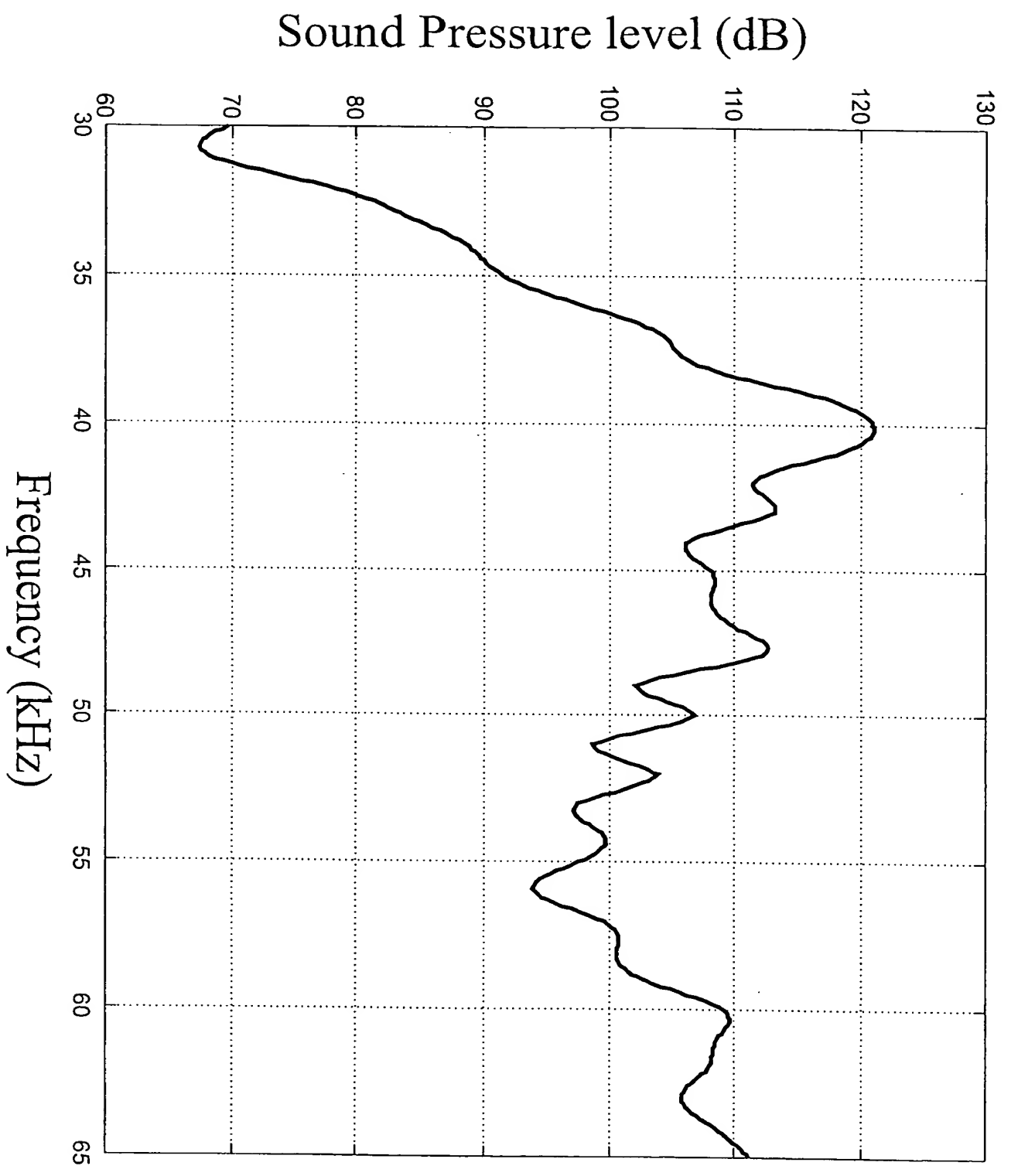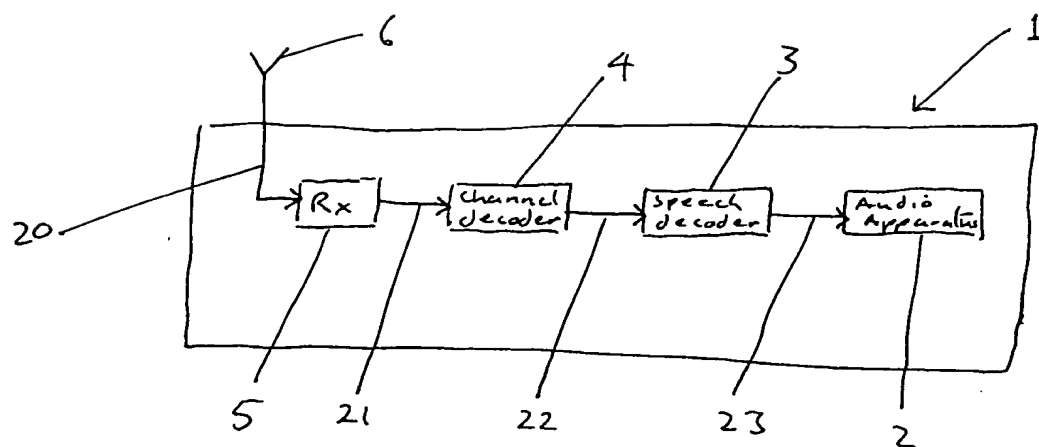
15

(Figure 4)

Relative sound pressure level (dB)

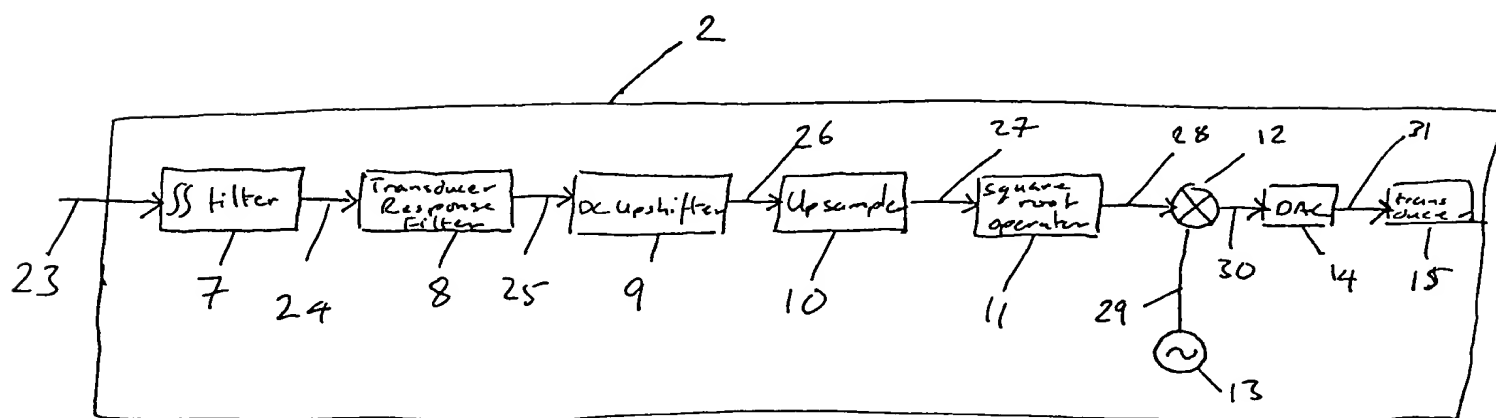Frequency (kHz)

Figure 1
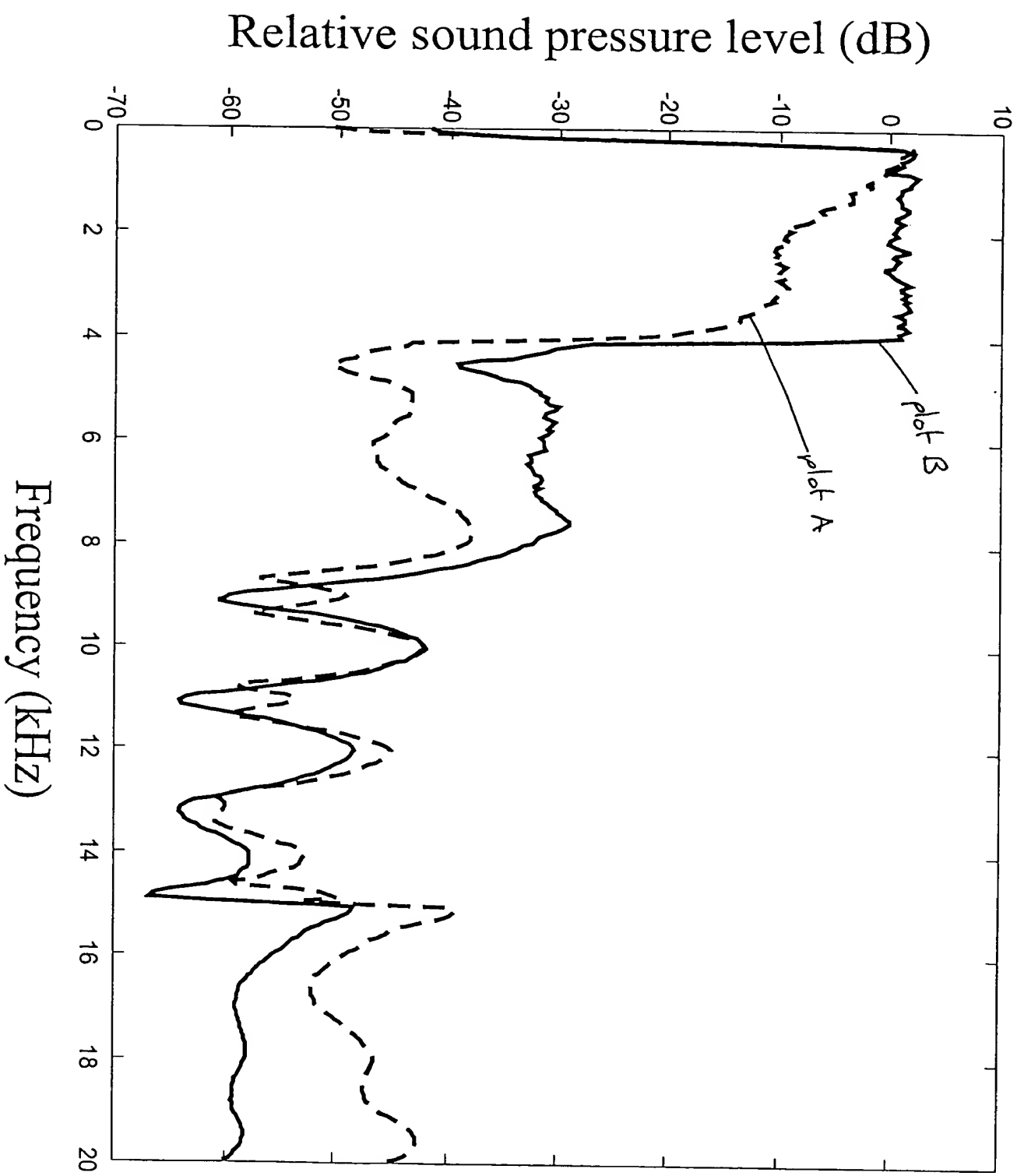
plot A

plot B

Figure 2

Figure 3

Figure 3

Figure 4

Figure 4

Relative sound pressure level (dB)

Frequency (kHz)

Figure 5

plot B

plot A